Predicting vegetation buffer efficiency in reducing runoff transport of sediments and nutrients

Hossein Ghadiri[1] – Janet Hussein – Calvin Rose – Bofu Yu – Mahin Abedinia

[1]Australian River Institute, Griffith University, Nathan 4111, Australia. Tel: ++61 7 37355175, Fax: ++61 7 37357459; Email: H.Ghadiri@griffith.edu.au

1. Abstract

Vegetative buffer strips are widely used as a conservation measure to reduce erosion and transport of sediments and associated pollutants across landscapes. Buffers generally reduce sediment and pollutant loads through a combination of deposition and infiltration processes. The physical processes involved in sediment deposition by a stiff Vetiver grass buffer strip at low flow rates (sub-critical) were examined in a series of experiments carried out in a 1x6m flume of a rainfall simulator. Experiments were carried out on three different soils introduced to flow path as slurry upstream of the Vetiver strip at different slopes and water and sediment profiles were measured at various time intervals. The strip caused a region of increased flow depth (backwater), upstream of the buffer which increased in depth and decreased in length with increasing slope. As slope increased, sediment was deposited closer to the grass strip, moving into the grass strip at 5% slope. The buffer strip was less effective in reducing sediment transport as slope increased and differences between slopes were significant. These experiments quantified the reduction in sediment and particulate-sorbed nutrients from overland flow and data were used to test the newly developed model of GUSED-VBS for assessing and predicting buffer efficiency in trapping sediment and sorbed nutrients. Unlike other models, GUSED-VBS simulates the evolution of the deposited layer by dynamically adjusting the bed elevation, the water profile and the flow velocity as a result of sediment accumulation. The model successfully predicts water and sediment profiles as well as masses of deposited sediment and sorbed nutrients.

2. Introduction

Soil erosion and runoff losses of sediment and nutrients from agricultural lands are major sources of water pollution. Vegetative buffer strips are used world-wide to reduce sediment and pollutant fluxes from moving off site and into waterways. A variety of buffer types are employed, ranging from trees along riparian zones, short grass filters in urban storm-water drains to stiff grass hedges at field edges or along waterways. These buffers remove sediments and pollutants through a combination of settlement, filtration and adhesion ((Newham et al., 2005). Of particular interest in our study is the reduction of sediment delivery due to net deposition upslope of stiff grass buffers. Such a buffer is very effective in causing settling-out of sediments, together with particulate-sorbed nutrients and pollutants. The strip retards surface flow, causing a backwater immediately upslope of the strip (Fig 1), with a corresponding reduction in flow velocity. As sediment-laden flow reaches this ponded area, the coarser material with higher settling velocity is deposited. Very fine material may remain in suspension and move through the buffer. Vetiver grass is typically employed for these hedges, as it has an erect, stiff growth and a strong rooting system (Truong, 1999; Sobey, 2006). This grass was used in our experiments as shown in Fig 1.

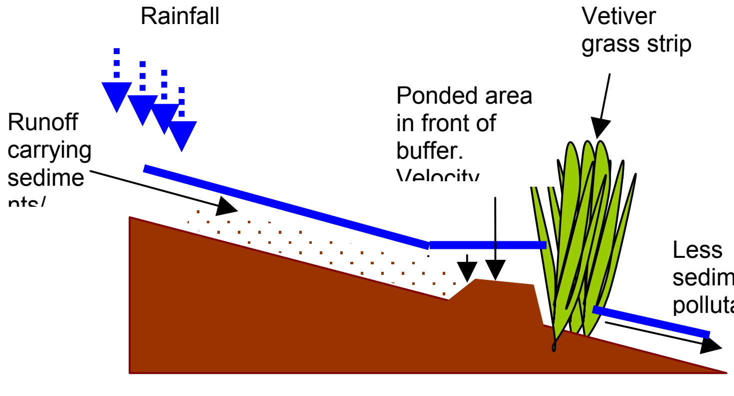

Figure 1 Processes involved in sediment reduction by a vetiver grass strip

The hydrology and the reduction of particulate and dissolved material occurring in or before the barrier strips have been examined in a number of studies (Dabney et al., 1995; Rose et al., 2003) and various models have been proposed to describe these processes (Deletic, 2001; Newham et al., 2005). These models however have many limitations including inability to deal with sediments of a wide variety of sizes and concentrations, not explicitly modelling the settling process in the backwater, and not taking into consideration time dependency of deposition process. Because of the settling process and flow adjustment in response to sediment accumulation in the backwater region, the buffer strip efficiency is time-dependent and changes as deposition builds up in the backwater region, which none of these models are capable of simulating. This paper tests a new modelling approach based on the work of Rose et al. (2003) to couple the hydraulics, sediment deposition and subsequent adjustment to bed topography to simulate the built-up of sediments in the backwater zone and its effect on flow conditions and the transport of sorbed and suspended sediments and nutrients.

3. Methods and Materials

Three Australian soils of contrasting texture were used for this study, a Podzol, a Ferralsol and a self-mulching Vertisol. The Podzol is the coarsest of the three soils, consisting primarily of coarse sand-size particles with little aggregation. The Vertisol and Ferralsol are both classified as clay textured but the Vertisol has a larger clay fraction (Table 1). The settling velocities of the inflow sediments were in the order of Podzol >Ferralsol >>Vertisol. The Ferralsol had an unexpectedly high settling velocity due to the preponderance of large stable aggregates in the soil.

Table 1 Analytical data for three soils used in experiments

Property	Podzol	Ferralsol	Vertisol
Sand (2.00-0.02 mm) (%)	90	36	13
Silt (0.02- 0.002 mm) (%)	4	21	23
Clay (<0.002 mm) (%)	6	43	64
Soil textural class	Sand	Clay	Clay
Mean settling velocity of inflow sediment (m s^{-1})	0.043888	0.03654	0.00966
Wet density of sediment (kg m^{-3})	2500	1600	1500
Cation Exchange Capacity ($mmoles_+$ kg^{-1})	97	157	643

The experiments were carried out in the 6m long by 0.3m wide section of flume of the GUTSR (Griffith University Tilting flume Simulation Rainfall) facility. A densely grown 0.3m x 0.3m bed of Vetiver grass was inserted in the flow path one metre from the exit end of the flume. As the floor of the GUTSR is impermeable, sediments were removed from flow by settling alone. Replicated experiments were conducted for each soil at 1, 3 and 5 % slopes. After stabilization of flow, a soil slurry was injected into flow at one minute intervals for a 40 minutes period using an automatic dispenser.

Four samples were collected from the dispenser (inflow) for each soil and analysed for particle size distribution and total sediment concentration.. Outflow samples were collected at 2 min intervals during each run, and sediment concentrations determined by oven drying. The rate of sediment deposition in front of the vetiver strip was measured using small zinc tags (20 x 20 x 1 mm) introduced into the flow on top of depositing sediment at different distances and times upstream of the buffer. At the end of the run the elevation of the new water surface was again measured, using dyed PVC strips. Depths to the tags imbedded in the sediment were recorded, and then samples of the sediment were taken from different distances upstream of the Vetiver strip. The deposited sediment samples were analysed for particle size distribution by wet sieving and pipette analysis.

4. Results and Discussion

Flows in the flume upstream of the Vetiver strip, were sub-critical, with Froude numbers of 0.60. The digitized data relating to flow/deposited sediment depths were recorded, as illustrated in Fig. 2 for one of the Podzol replicates at 5% slope. Upslope distances from the start of the Vetiver strip are presented as negative values. The 'water start' line in Fig.2 shows the water profile depths at the start of this particular experiment and indicates that the grass strip retarded flow, causing a backwater or 'ponded' area with an increased flow depth upslope of the vetiver strip. A maximum flow depth of 0.025 m was recorded for this replicate just upstream of the vetiver strip and the backwater zone extended -0.40 m (upstream) of the strip. Upon the addition of soil, deposition occurred in the ponded zone due to reduced flow velocity. Larger particles/aggregates with high settling velocities deposited in the backwater region. After 40 minutes, the sediment ('sediment end' in Fig.2) reached a final maximum height of ~12 mm at –0.5 m in front of the vetiver strip and extended upstream to –0.8 m. The backwater zone thus grew in length and height due to net deposition, extending upstream to a final value of ~0.85 m ('water end' Fig. 2) and flow depth over this sediment reached a maximum recorded height of 57 mm at the start of the vetiver strip. Water and sediment profiles were recorded for all the replicates and the results were analysed. Backwater lengths were found to increase and its depth decrease with decreasing slope. Sediments were primarily deposited in front of the vetiver strip in a low mound, as illustrated in Fig. 2, with very little deposition in, or after, the strip. The Podzol and Ferralsol were deposited further upstream of the vetiver strip, in contrast to the Vertisol which was deposited close to the vetiver strip. This is to be expected, as the finer sediment of the Vertisol has a lower settling velocity (Table 1) and is carried further towards the strip by the flow, before being deposited. Similarly shaped hydrology profiles with vetiver or barrier strips have been recorded in flumes by Ghadiri et al. (2001) and Dabney et al. (1995). for supercritical flows.

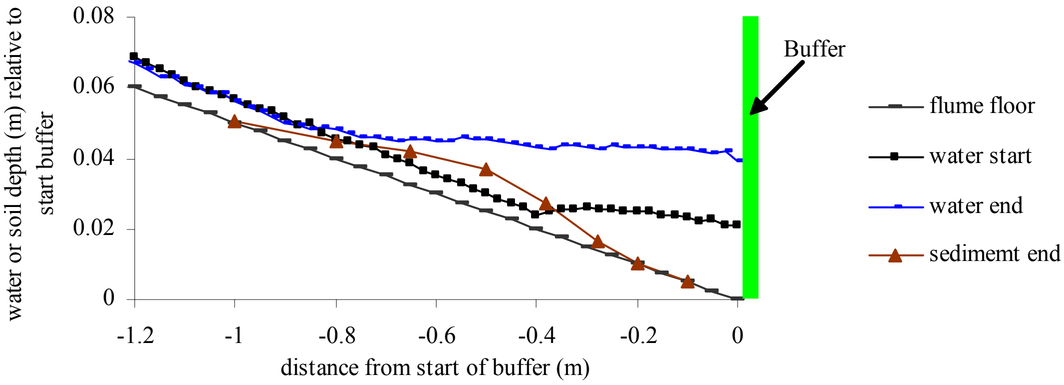

Figure 2 Water and sediment profiles for the Podzol

Sediment loads were significantly reduced by the vetiver strip, indicating that between 88% to 97 % of the inflow sediments were deposited. Trapping efficiency was therefore very high under these subcritical flow conditions, decreasing somewhat with increasing slope and flow rate. The greatest reduction was measured for the coarse Podzol and there was a significant difference in sediment load between the Podzol and Ferralsol. It has been confirmed in a number of field studies on grass buffer strips that the high sediment removal efficiency happens at moderate slopes and flows.

The GUSED-VBS model (Griffith University Soil Erosion & Deposition model-Vegetated Buffer Strip) developed by this group (Hussein et al., 2007) was used to simulate the water and sediment profiles for the given experimental conditions and these were compared to measured data. The parameters that indicate the closeness of fit of the simulated to measured data, including the coefficient of model efficiency, *Ec*, the Root Mean Square Error (*RMSE*) and relative magnitude of errors all indicate that the simulated water profiles matched the measured values fairly closely for all slopes.

The simulated sediment profiles were similar in overall shape to the measured data for all the Vertisol runs, such as the example shown in Fig.3, but indicated deposition closer to the grass strip than was measured for the Podzol and Ferralsol. The closeness of fit parameters indicate greater differences between observed and simulated data. The simulated sediment profiles are therefore not as good a fit as the water profiles, but are within an acceptable range. The measured total mass of sediment deposited in the backwater region of the grass strip also compared well with the simulated data. Therefore overall the model successfully simulated the changing hydrology during deposition, total sediment deposition and the location of fine sediment around the buffer strip, but was less successful at simulating the location of the deposition for the coarser sediments.

Fig.4 shows an example of simulated versus measured nutrient removal for particulate-sorbed P. The simulated data follows a similar trend to the measured data. The N and C simulations were somewhat similar. The model thus slightly under-predicts the nutrient retention by the vetiver buffer. Further work is underway to test the model with field data. The simulation of nutrient reduction by this process-based model is however an important first step towards the examination of spatial and temporal dynamics of nutrients in buffers and possible incorporation into the kind of conceptual model proposed by Dorioz et al. (2006)

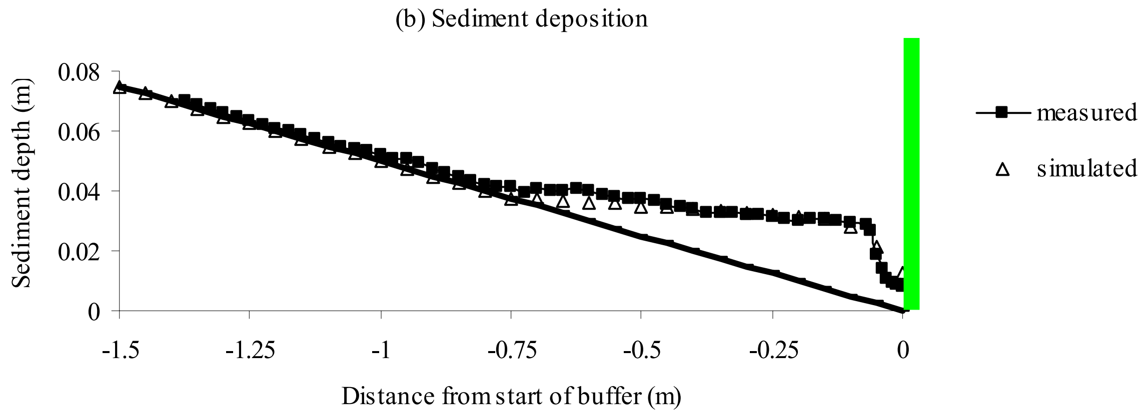

Figure 3 Measured and simulated sediment profiles for the Vertisol at 5 % slope

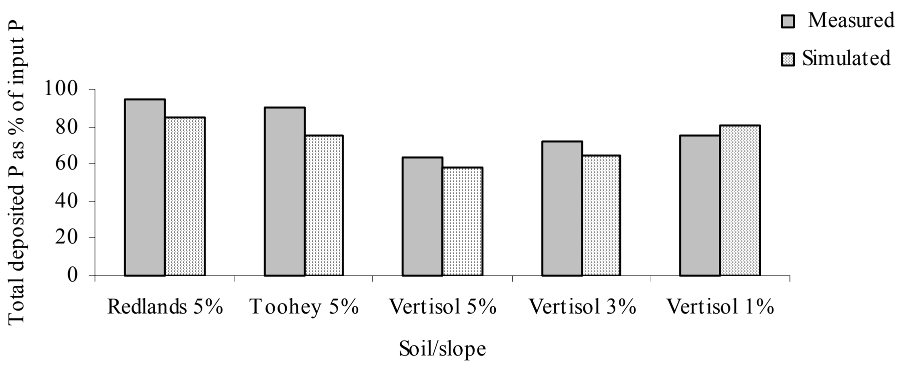

Figure 4 Comparison of simulated versus measured % of total P in deposited sediment

5. References

Dabney, S.M., Meyer, L.D., Harmon, W.C, Alonso, C.V. and Foster, G.R., 1995. Depositional patterns of sediment trapped by grass hedges. Transactions of ASAE 38, 1719-1729.

Deletic, A., 2001. Modelling of water and sediment transport over grassed areas. Journal of Hydrology 248, 168-182

Deletic, A., 2005. Sediment behaviour in runoff over grassed surfaces. Journal of Hydrology 301, 108-122.

Dorioz, J.M., Wang, D., Poulenard, J. and Trevisan, D. 2006. The effect of grass buffer strips on phosphorus dynamics – a critical review and synthesis as a basis for application in agricultural landscapes in France.

Ghadiri, H., Rose, C.W. and Hogarth, W.L., 2001. The influence of grass and porous barrier strips on runoff hydrology and sediment transport. Transactions of the American Society of Agricultural Engineers 44, 259-268.

Hussein, J., Yu, B., Ghadiri, H. and Rose, C.W. 2007. Prediction of surface flow hydrology and sediment retention upstream of a vetiver buffer strip.. Journal of Hydrology 338: 261-272.

Newham, L.T.H., Rutherford, J.C. and Croke, B.F.W. 2005. A conceptual model of particulate trapping in riparian buffers. CSIRO Land and Water Technical Report 21/05. CSIRO Land and Water Canberra,. Australia.

Rose, C.W., Yu, B., Hogarth, W.L., Okom, A.E.A.and Ghadiri, H. 2003. Sediment deposition from flow at low gradients into a buffer strip – a critical test of re-entrainment theory. Journal of Hydrology 280,33-51

Sobey,I. 2006. Utilisation of Vetiver System in Disaster Mitigation in Central Vietnam. Vetiver System: Disaster Mitigation and Environmental Protection in Vietnam. Proceedings of the. Regional Vetiver Conference, Cantho City, Vietnam January 2006.

Truong, P.N.V.1999. Vetiver grass technology for flood and stream bank erosion control. Proceedings of the International Vetiver Workshop Nanchang, China, October 1999.